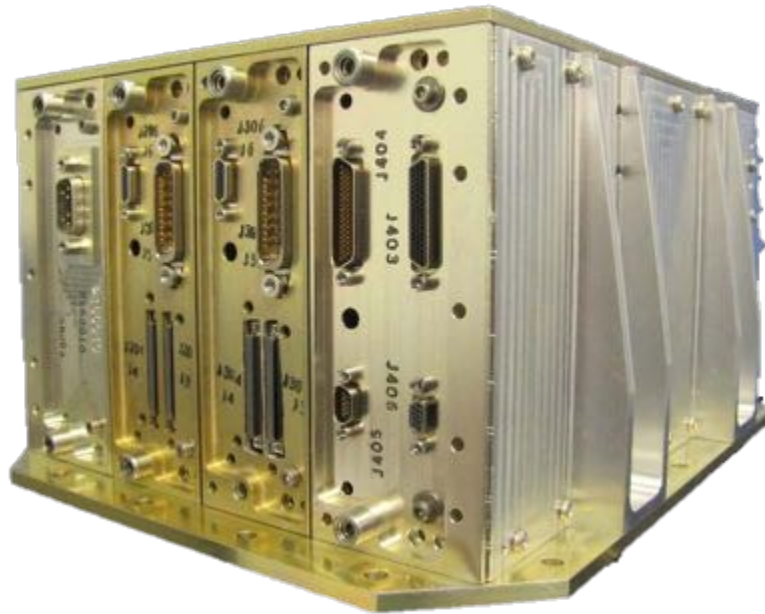


SpaceCube Technology Brief

Hybrid Data Processing System



Dave Petrick, 587/Chief Engineer
Science Data Processing Branch
NASA Goddard Space Flight Center

SpaceCube Overview

Heritage

- GOAL: close the gap with commercial processors while retaining reliability
- Started in 2006 at GSFC as R&D
- **38+ Xilinx device-years on orbit**
- 22 Xilinx in space by 2016
- 8 systems in space by 2016
- Various R&D efforts on hardware acceleration

Hybrid Data Processing

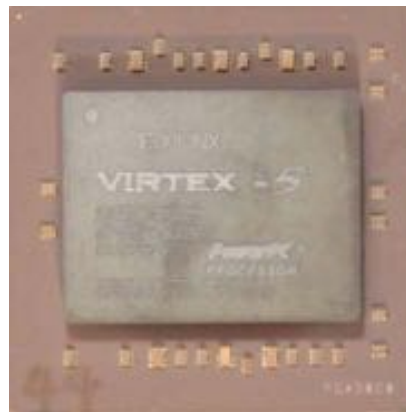
- Parallel data processing:
 - FPGA + DSP + Processor(s)
- SpaceCube can move **3,000x** more data than a sequential processor per clock cycle

**SpaceCube is a
Mission-Enabling Technology**

SpaceCube v2.0

- Currently TRL-7
- Leverages 10 years of design heritage and operation experience
- **\$10M+ of NRE**
- Adopted by SSCO for all missions
- IPC 6012B Class 3/A PWB Reliability
- Modular: 9 Mission-Unique I/O cards
- **Run-Time Reconfigurable**

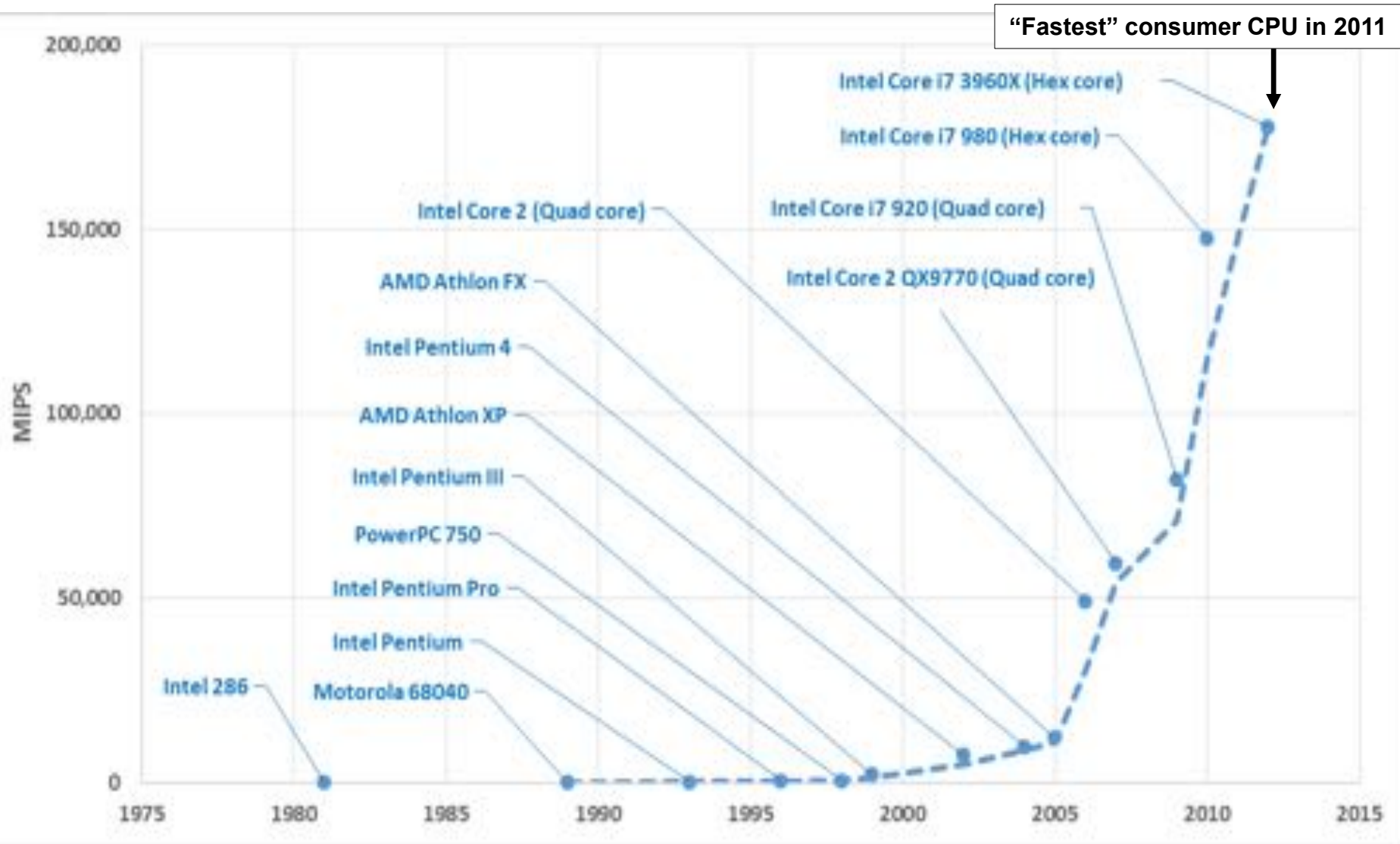
Xilinx Virtex-5 FPGA



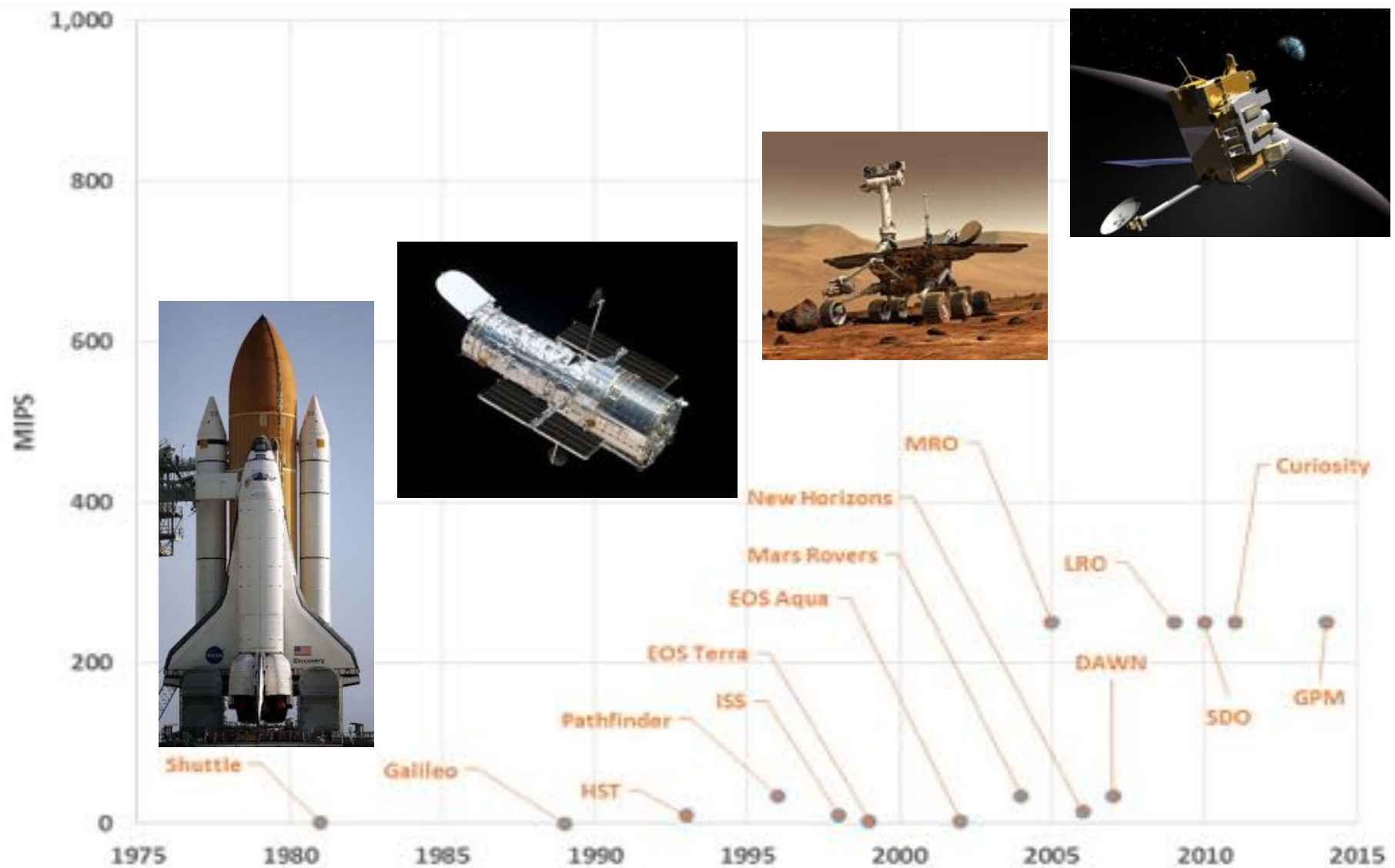
SpaceCube v2.0



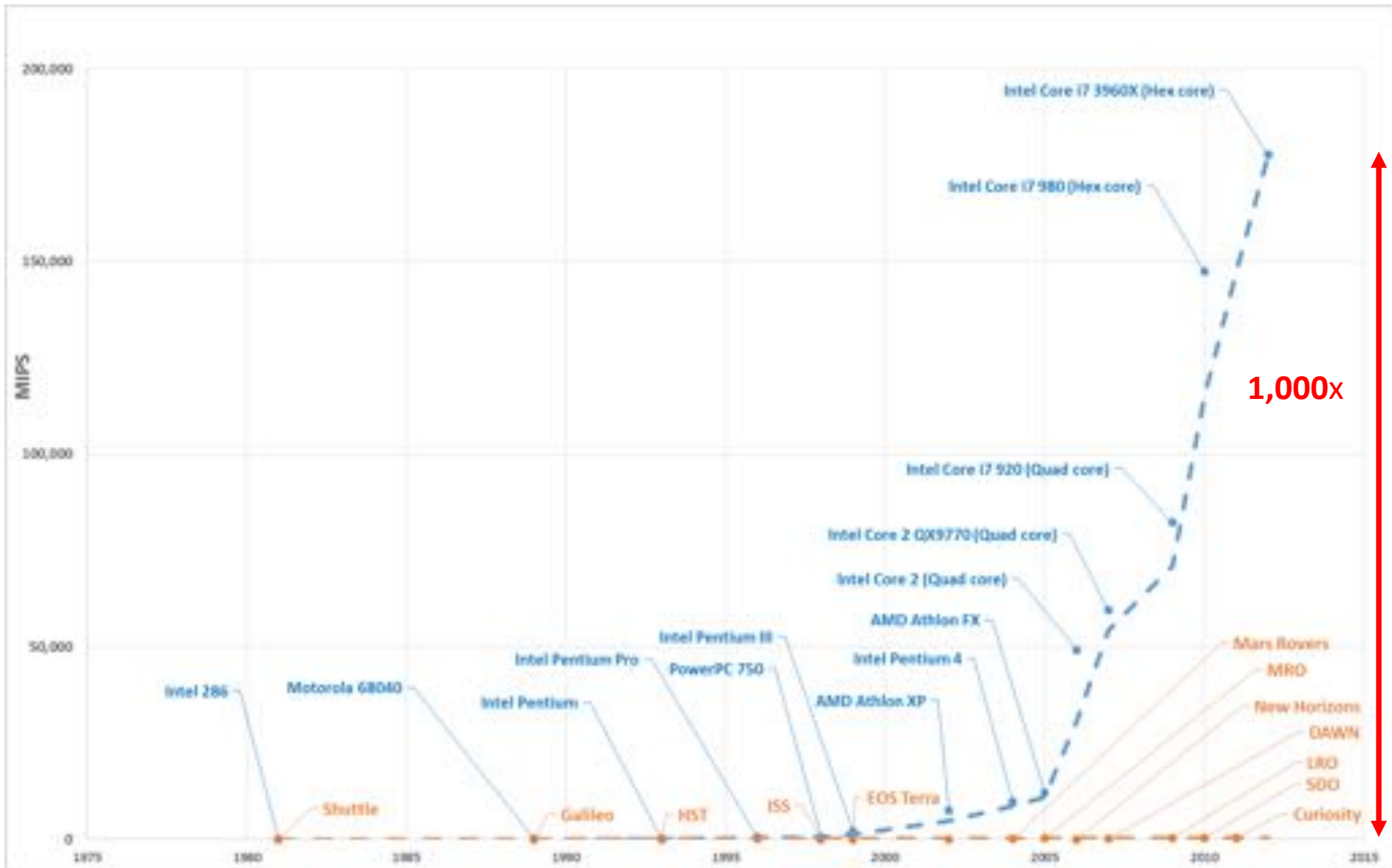
Commercial Processor Trend



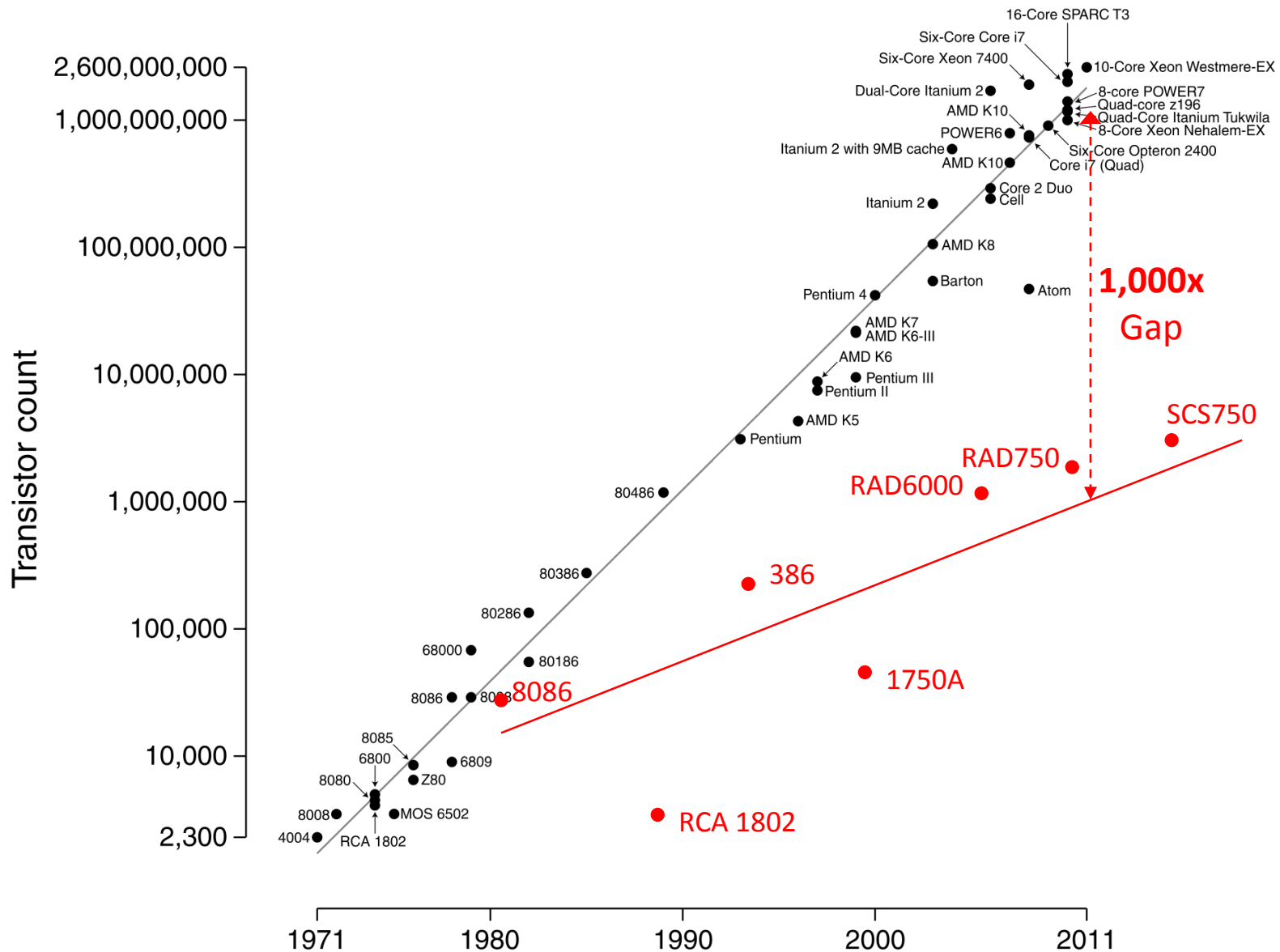
Space Processor Trend



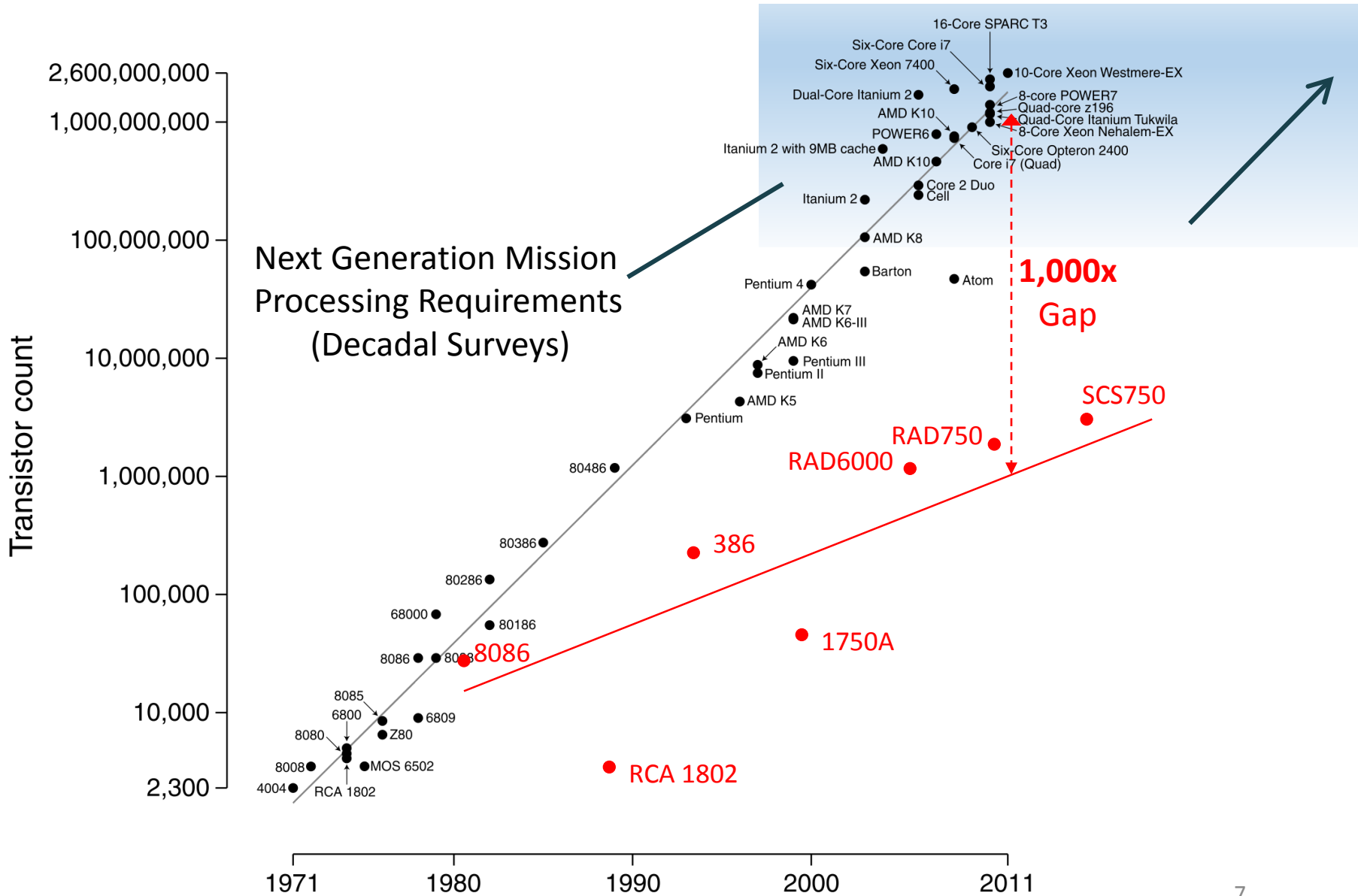
Processor Trend Comparison



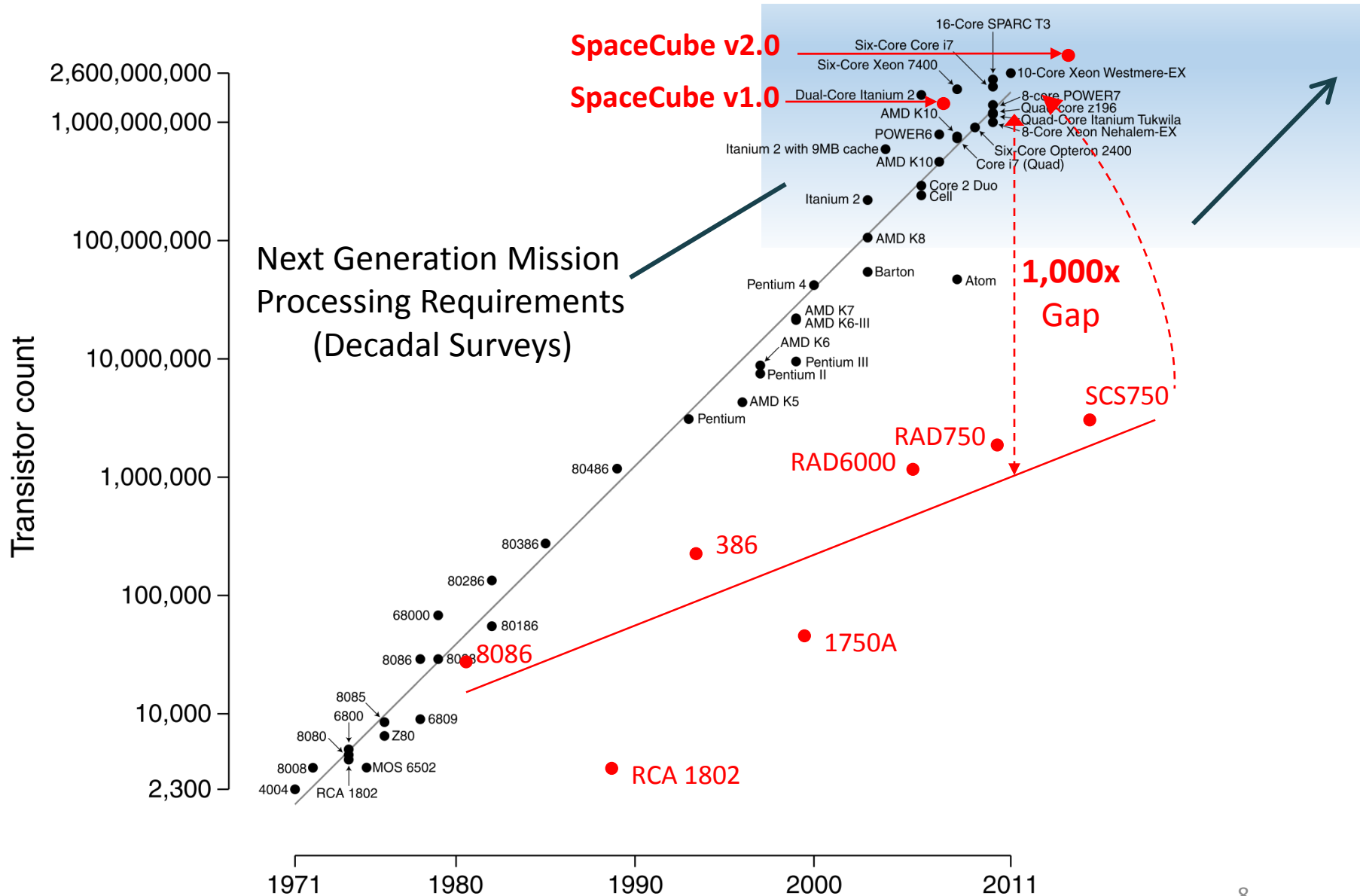
Processor Trend Comparison



Future Space Processing Requirement



SpaceCube Closes the Gap



SpaceCube Family Overview

v1.0



2009 STS-125
2009 MISSE-7
2013 STP-H4
2016 STP-H5
2018 STP-H6

v1.5



2012 SMART (ORS)

v2.0-EM



2013 STP-H4
2016 STP-H5

v2.0-FLT



2017 RRM3
2018 STP-H6 (NavCube)
2018 NEODaC
2020 Restore-L
Many NASA proposals

v2.0 Mini

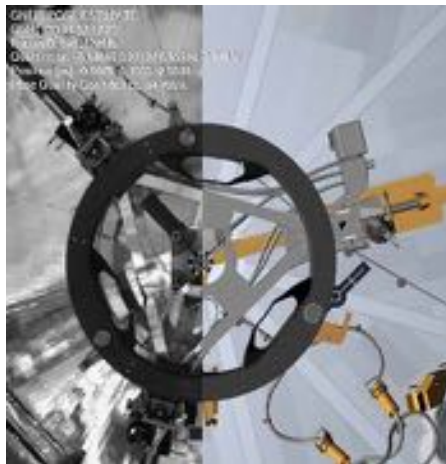


2016 STP-H5
Many NASA proposals

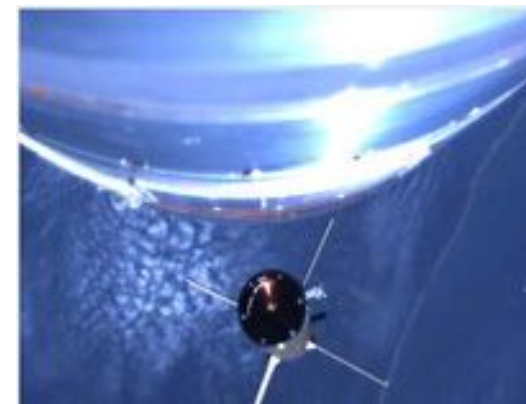
Example SpaceCube Processing



Real-Time Image Tracking of Hubble



Fire Classification



Gigabit Instrument Interfacing

Xilinx ISS Radiation Data



Spectrometer Data Reduction

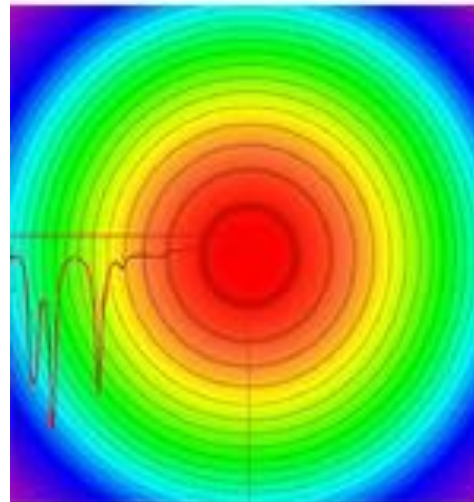
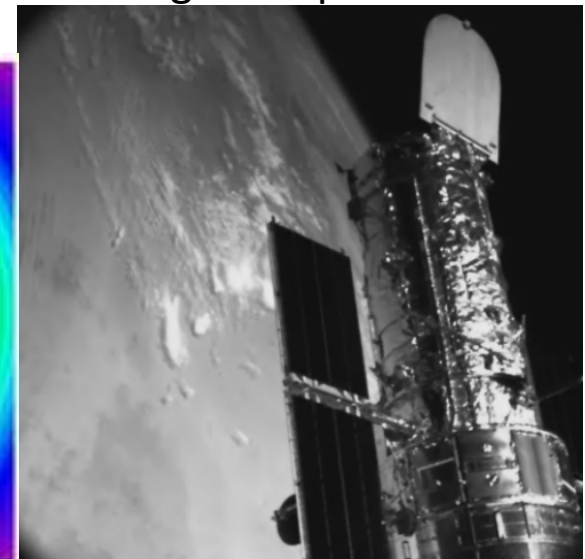


Image Compression



On-Board Image Processing

- Successfully tracked Hubble position and orientation in real-time operations
- FPGA Algorithm Acceleration was required to meet 3Hz loop requirement

Rendezvous

Deploy (Docking Ring)

→ Typical space flight processors are 25-100x too slow for this application

SpaceCube v2.0



Restore-L/RRM3/NEODaC Computer



SpaceCube Processor Card



SpaceCube Backplane Card



SpaceCube Power Card

Processor Card

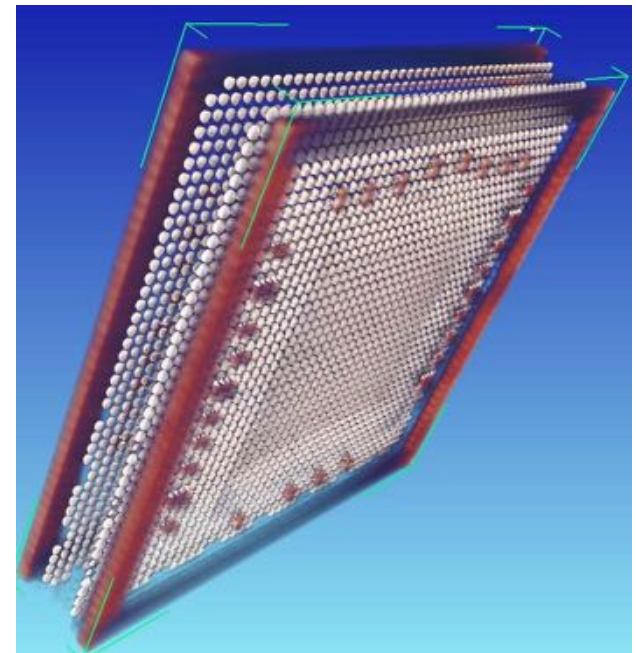
Power Draw: 6-15W

Weight: 0.98-lbs

22 Layers, Via-in-Pad

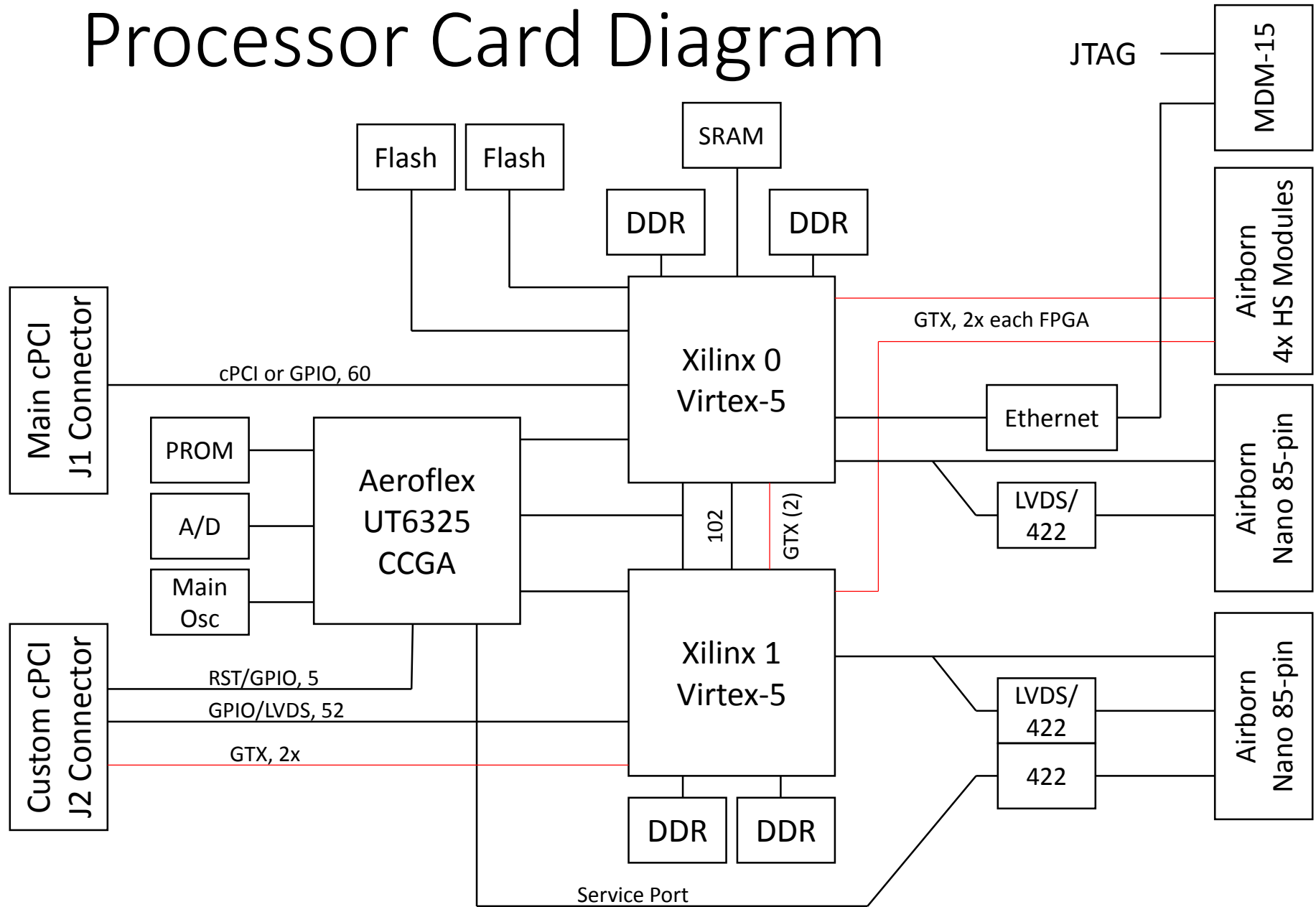
IPC 6012B Class 3/A

- 2x Xilinx Virtex-5 (QR) FX130T FPGAs
- 1x Aeroflex CCGA FPGA
 - Xilinx Configuration, Watchdog, Timers
 - Auxiliary Command/Telemetry port
- 1x 128Mb PROM, contains initial Xilinx configuration files
- 1x 16MB SRAM, rad-hard with auto EDAC/scrub feature
- 4x 512MB DDR SDRAM
- 2x 4GB NAND Flash
- 16-channel Analog/Digital circuit for system health
- Optional 10/100 Ethernet interface
- Gigabit interfaces: 4x external, 2x on backplane
- 12x Full-Duplex dedicated differential channels
- 88 GPIO/LVDS channels directly to Xilinx FPGAs
- Mechanical support for heat pipes and stiffener for Xilinx devices



2014 Global Award: Most innovative design worldwide in the Military/Aerospace sector

Processor Card Diagram



TOP



BOTTOM



Example Mission-Unique I/O Cards

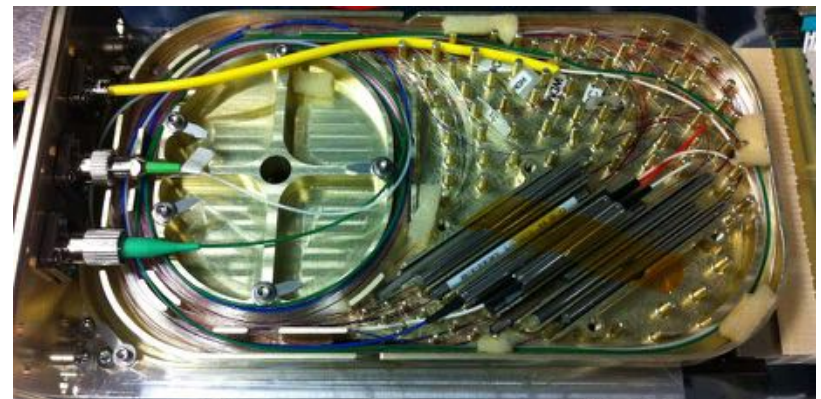
Restore-L Video/Spacecraft Interface Card



GPS RF Front-End Interface Card

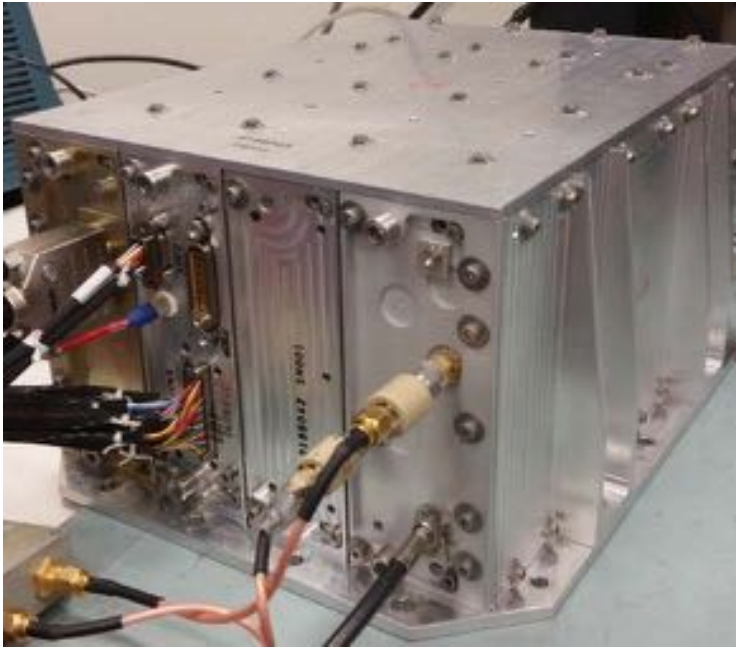


LIDAR Digitizer, Front-End, and Laser Card

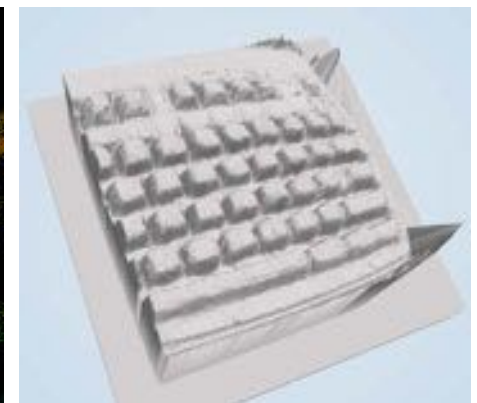
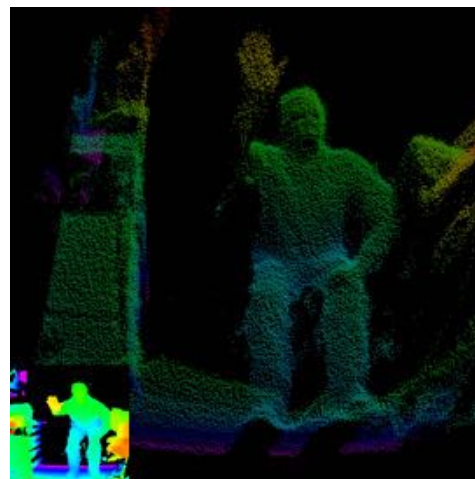
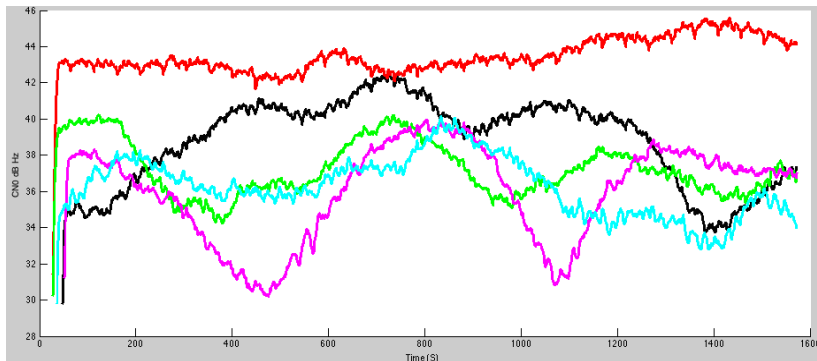
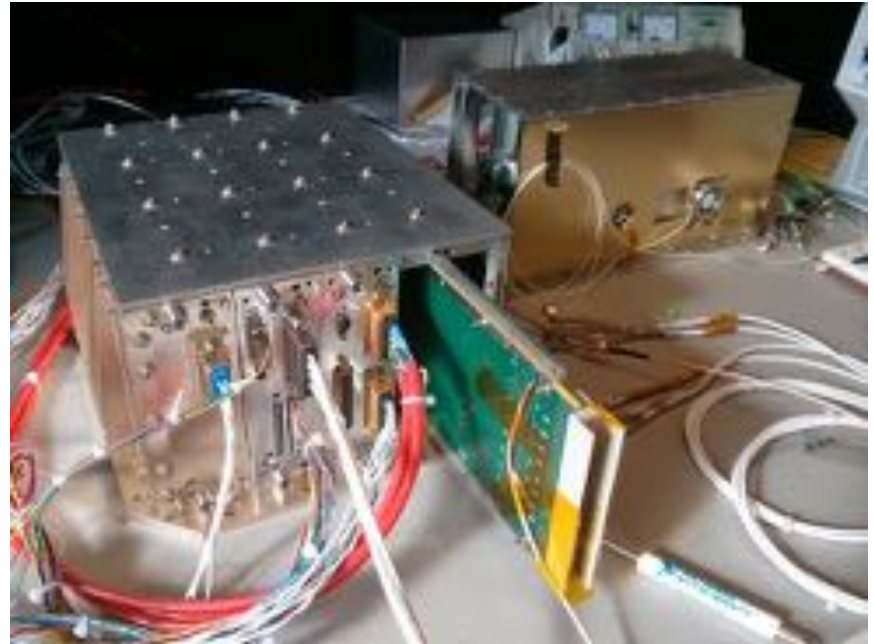


Spinoff Technologies

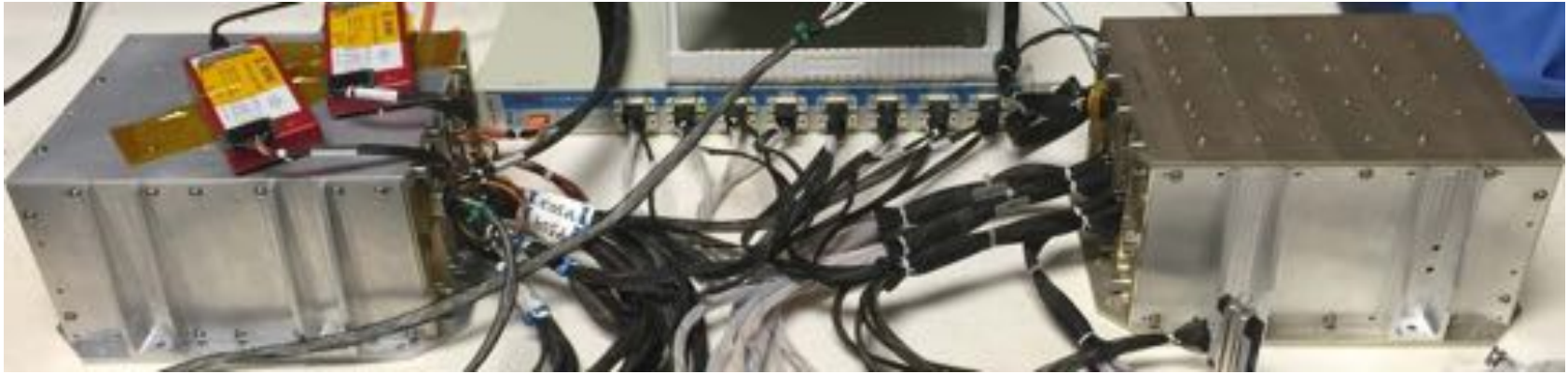
GPS Receiver – L1/L2C Tracking



LIDAR Instrument – Configurable Resolution



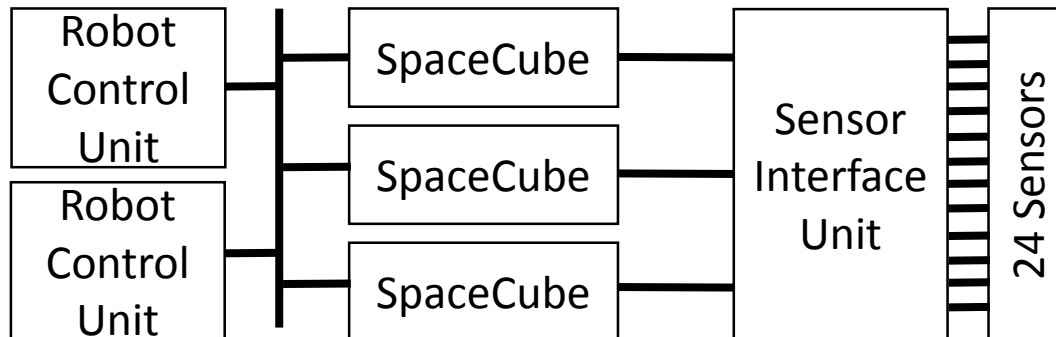
Restore-L Satellite Servicing Mission



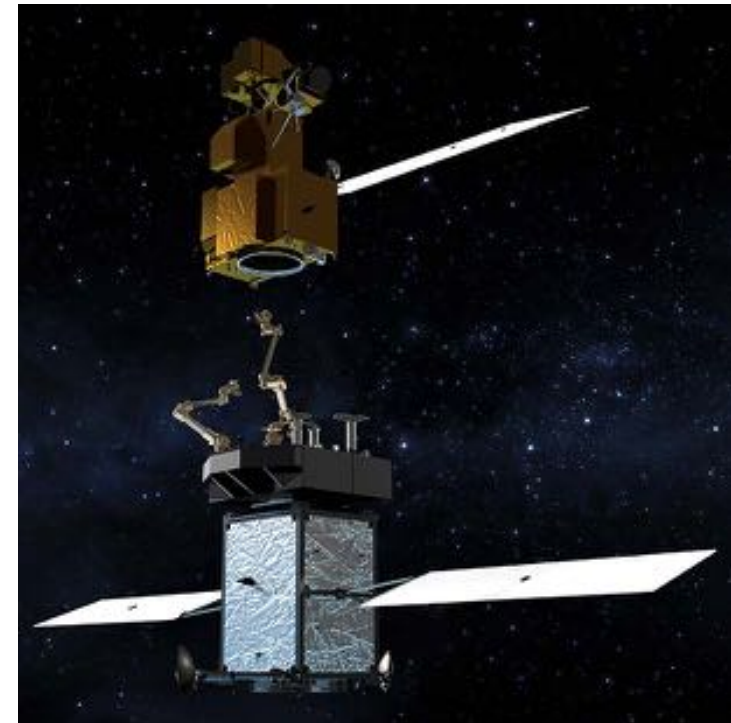
Restore-L Dual SpaceCube Payload Control Computers

High Level Requirements:

- Interface with Spacecraft and Payload Busses
- Interface with vision sensors
- Host Relative Proximity Operations application
- Host Robotic Manipulation Control application



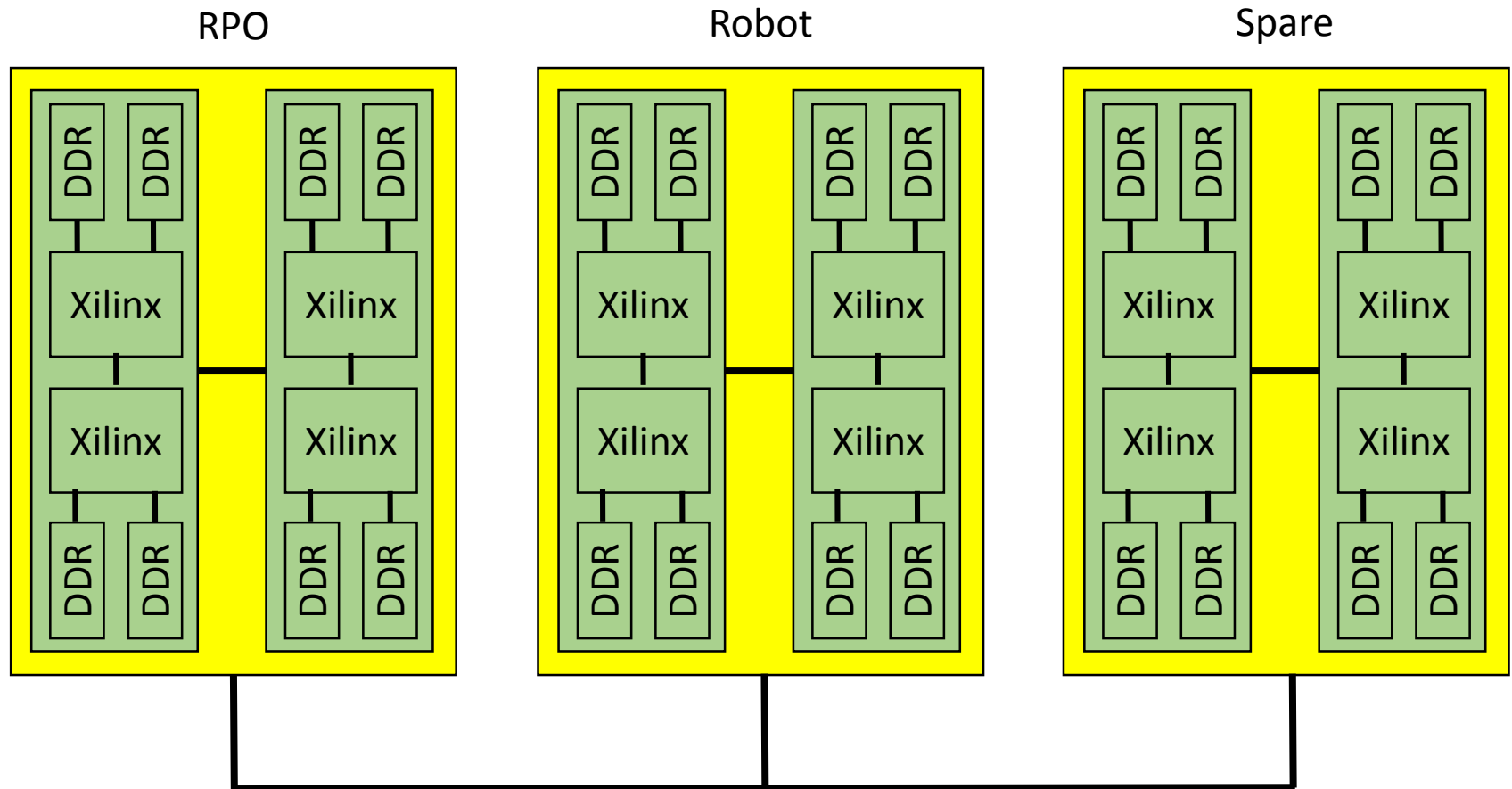
Restore-L will fly 21 Xilinx Virtex-5 FPGAs



Restore-L Capture of Landsat 7

What About Radiation Effects??

Restore-L SpaceCube Data Processing Architecture

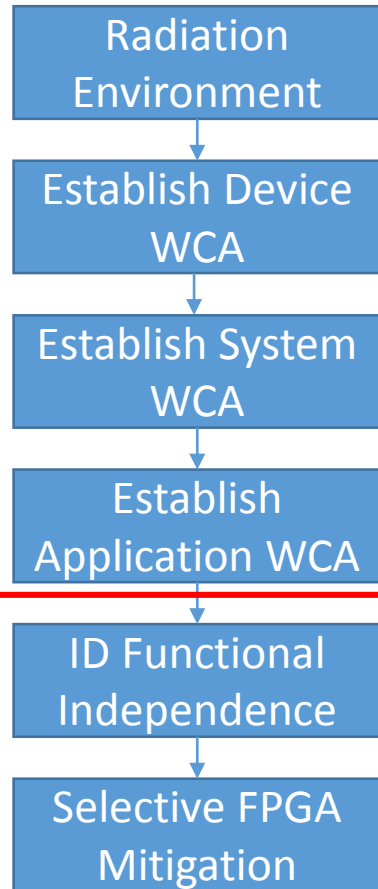


If Spare is “Cold”, then worst case error probability: $Pe(sys) = [8x Pe(Xilinx) + 16x Pe(DDR)]$

Establishing SEE Error Rates

NASA Risk Assessment

Assessment Process



Labor Intensive

Likelihood	Safety Estimated likelihood of Safety event occurrence	Technical Estimated likelihood of not meeting performance requirements
5 Very High	$(P_{SE} > 10^{-1})$	$(P_T > 50\%)$
4 High	$(10^{-2} < P_{SE} \leq 10^{-1})$	$(25\% < P_T \leq 50\%)$
3 Moderate	$(10^{-3} < P_{SE} \leq 10^{-2})$	$(15\% < P_T \leq 25\%)$
2 Low	$(10^{-5} < P_{SE} \leq 10^{-3})$	$(2\% < P_T \leq 15\%)$
1 Very Low	$(10^{-6} < P_{SE} \leq 10^{-5})$	$(0.1\% < P_T \leq 2\%)$

		100% Device Utilization WCA		Estimated Restore WCA Upset Rates		
Mode	Time (s)	Device WCA	PCC WCA	RPO PCC	RSW PCC	RPO + RSW
one orbit (96 minutes)	5760	0.484%	1.934%	1.074%	0.222%	1.296%
Rendezvous (30 min)	1800	0.151%	0.604%	0.336%	0.069%	0.405%
Capture (77 sec)	77	0.006%	0.026%	0.014%	0.003%	0.017%

Note: assumes BRAM Mitigation

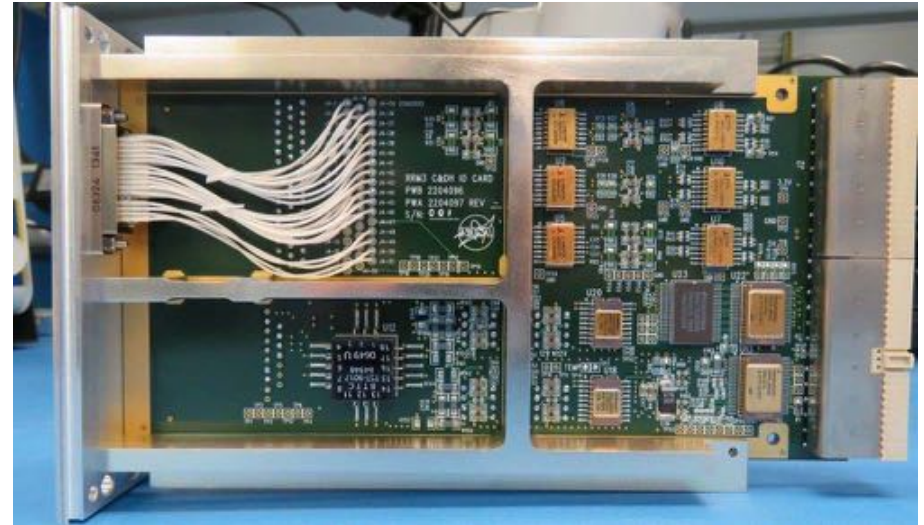
Note: Actual utilization for RPO and RSW PCCs as of 4/18/2016

Note: assumes RPO & RSW PCCs must be error-free for full operation

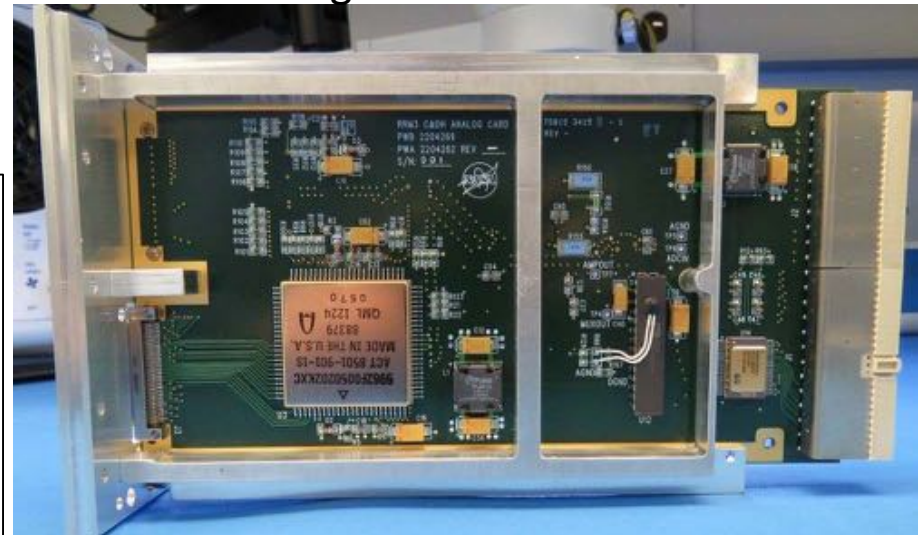
Robotic Refueling Mission SpaceCube



1553/Ethernet/Digital Card



Analog Card



High Level Requirements:

- Interface with ISS and RRM3 instruments:
 - Cameras, thermal imager, motors
- Monitor/Control cryocooler and fuel transfer
- Stream video data
- Motor control of robotic tools
- Host Wireless Access Point

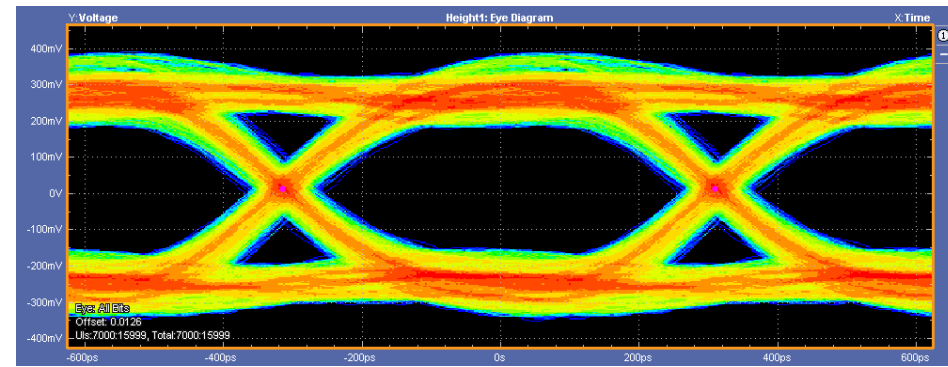
NEODaC Instrument Development

8x 3K x 3K detectors



Xilinx Driver: 1.6Gbps, 1300mV, 17%

- Detect and Characterize NEOs
- Working with “Partner” organization on complex detector instrument
- SpaceCube FPGAs being used to solve very challenging avionics requirements and host on-board data processing applications and compression
- Successful Detector readout with SpaceCube completed
- March 2018 Delivery

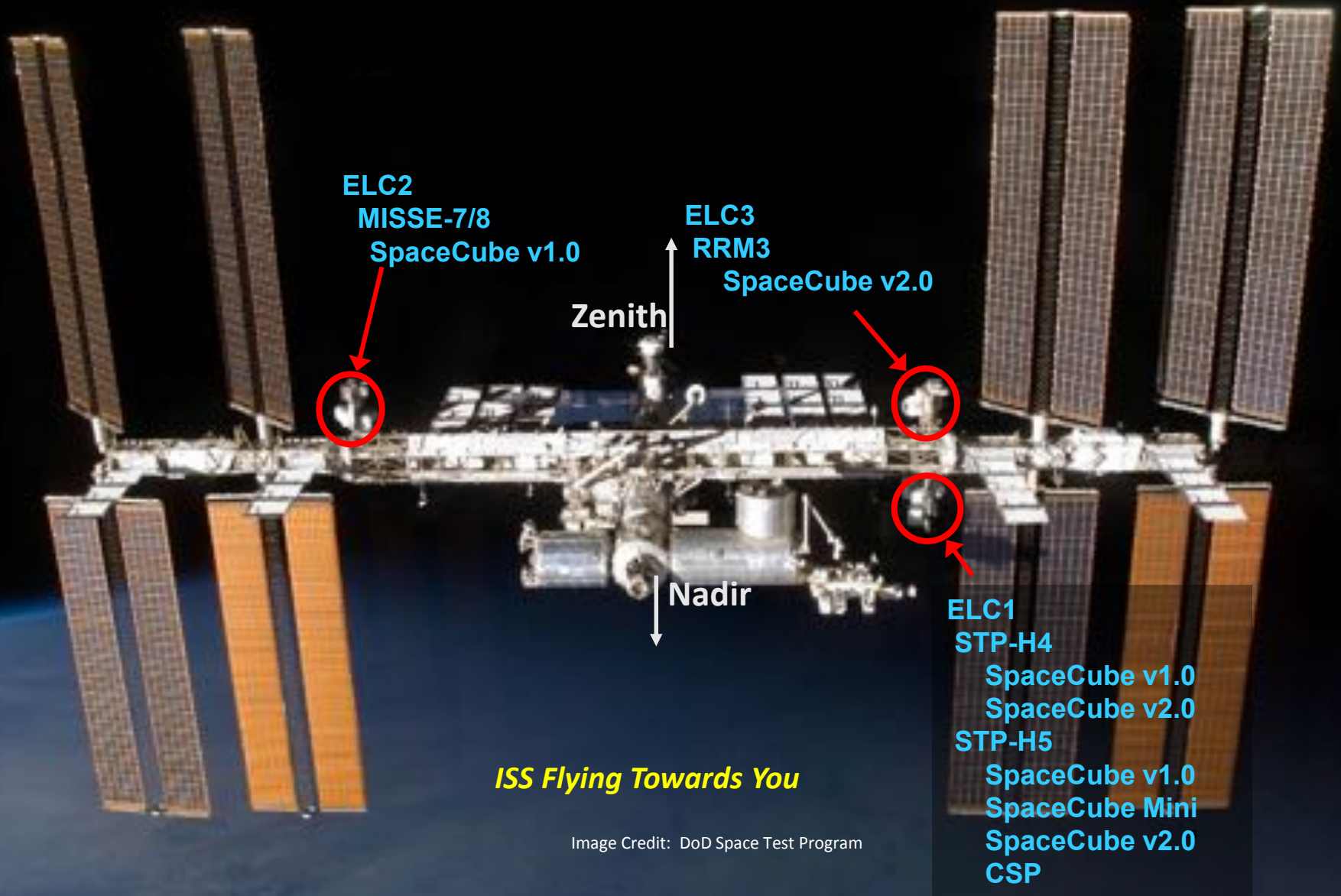


HSCSI Link Test Results

Transmitter Swing (mV)	Transmitter % Pre-emphasis	Test Duration	Bit Error Count	BER (*)
500	0	6hr	32	9.2E-13
500	8	18hr	0	9.6E-15
800	0	4hr	4	1.7E-13
800	25	20hr	0	8.7E-15
1300	17	20hr	0	8.7E-15
1300	0	19hr	52	4.7E-13

- Note: BER calculation assumes at least 1 error
- 58-hours of error-free transmission

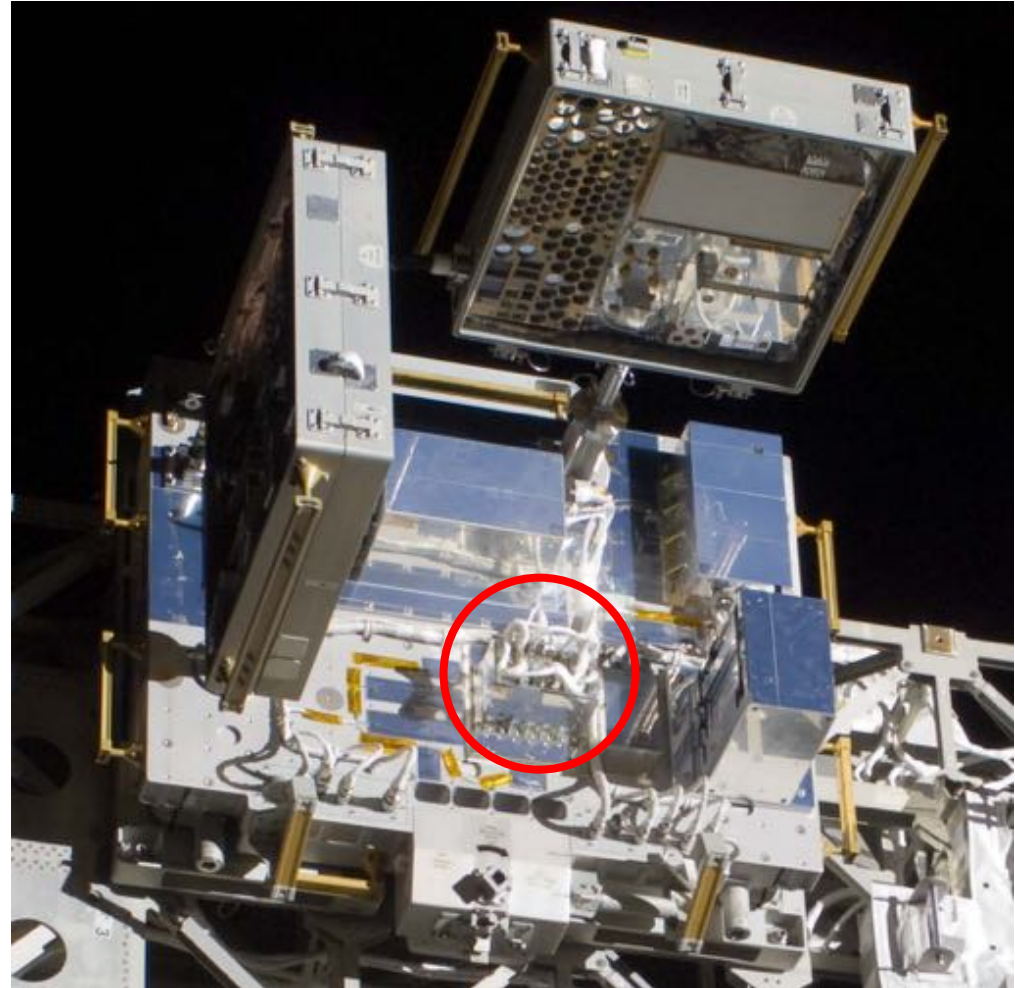
SpaceCube on the ISS



SpaceCube v1.0

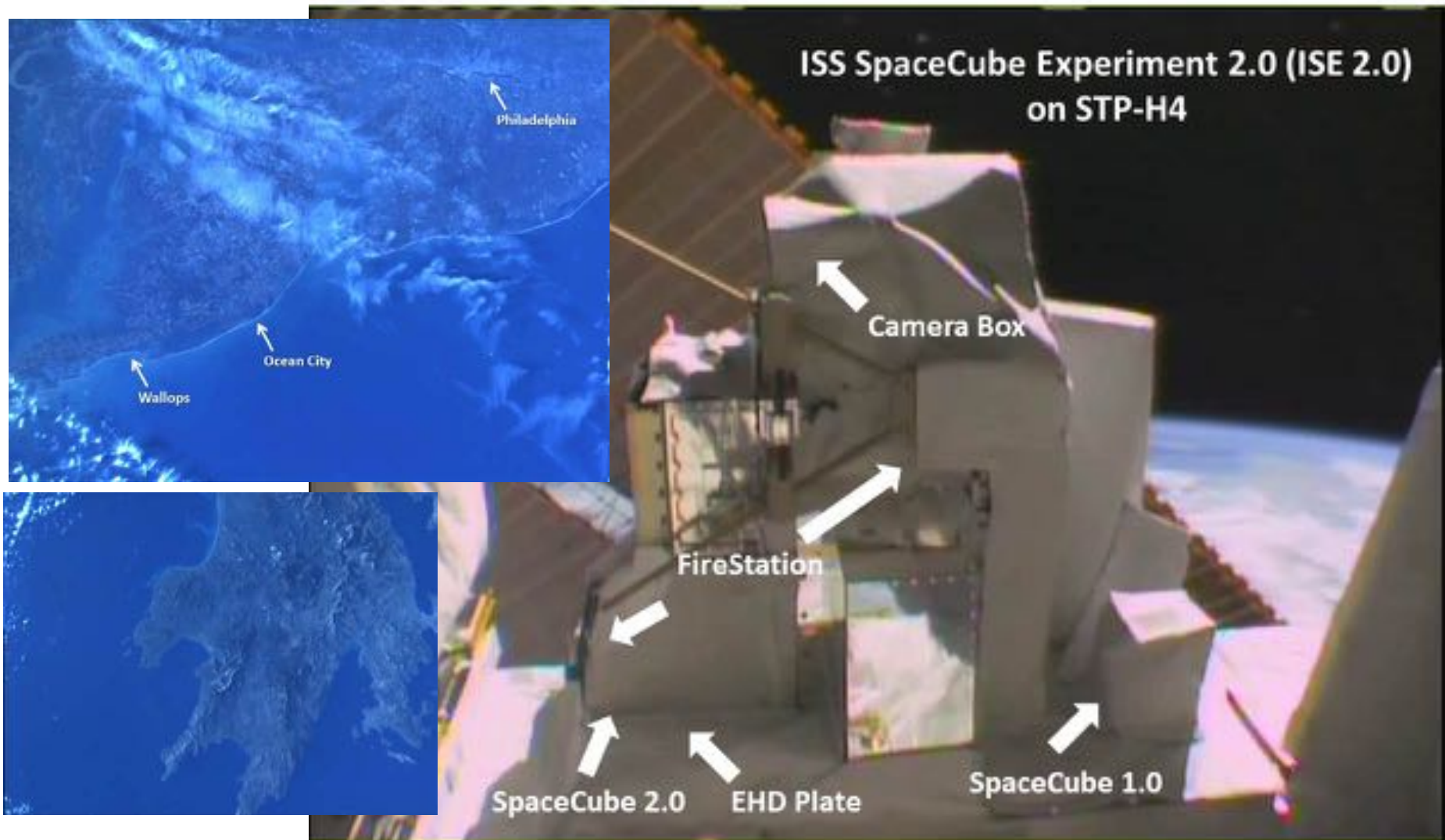
MISSE-7/8 ISS Payload

STS-125 Shuttle Payload Bay



- 7 years of operation
- 4x Virtex-4 XC4VFX60: 0.1 SEU/FPGA/Week
- 2x on-orbit file uploads and reconfiguration

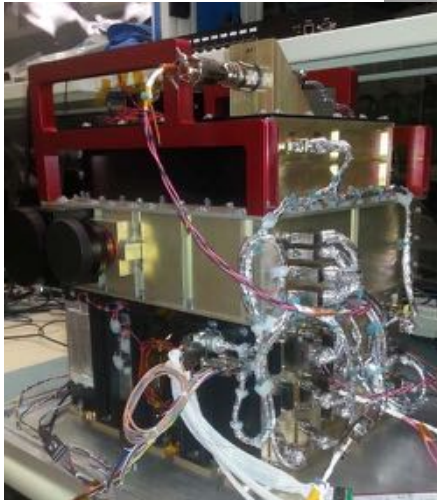
STP-H4 ISS Payload



2 years of operation. 3x Virtex-5 XC5VFX130T: 1 SEU/FPGA/Week
Successful on-orbit file upload and reconfiguration

STP-H5 ISS Payload

ISEM, SpaceCube Mini



SSCO Raven

SpaceCube v2.0 EM

SpaceCube v1.0 CIB

Photo Credit: DoD STP

The Space Test Program-H5 (STP-H5) external payload, a complement of 13 unique experiments from seven government agencies, is integrated and flown under the management and direction of the Department of Defense's Space Test Program.

SpaceX Launch Scheduled November 11, 2016

Questions?